chaos in electronic circuits

seeing is believing

Today some aspect of chaos theory is often seen in science magazines and even newspapers. Does it have any relevance to radio and other electronic circuits? Yes, it does.

By Chris Meadows G4KWH

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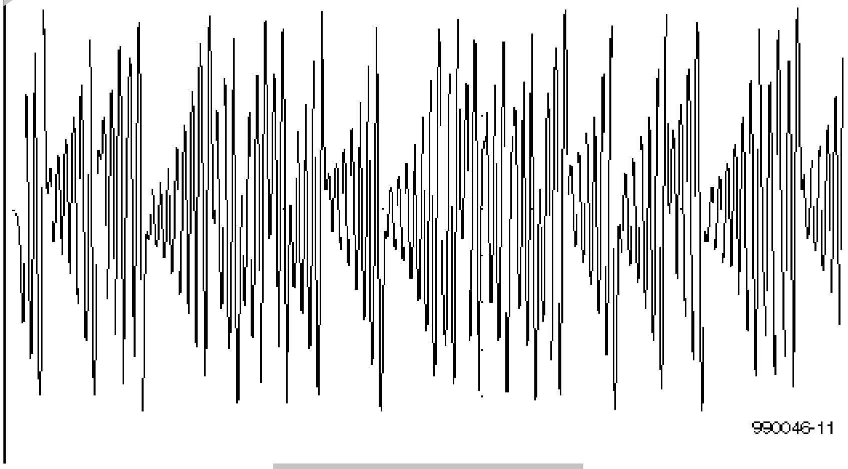

Figure 1. Trace of a chaos time diagram.

The term chaos may conjure up random uncoordinated movements of people in panic or the up and down movement of the stock market. In the scientific and engineering use of the term, chaos is not random in spite of the manner in which it shows itself. I hope you will be convinced of this by simulating or actually constructing the small chaotic electronic circuit given in this article.

What is chaos? How may it be defined? Two main tests can by applied to check for chaos. Firstly an electronic circuit may be exhibiting chaos if its output waveform shape can be significantly altered when a component value is changed by a small amount, say 1%. A typical chaotic time output waveform may be seen in **Figure 1**.

Secondly, if two different voltages (or currents) that exist in the circuit are able to produce a ‘strange attractor’, using the X-Y feature on an oscilloscope, then the circuit under test is behaving chaotically. This test depends on the interpretation of the image as a strange attractor. A strange attractor image is shown in **Figure 2**.

Why is the image strange? The picture we see exists in three-dimensional space. We are looking at a trace that never intersects itself; the loops (they are not circles) are infinitely deep but continually fold back, but never touch or join. For all of this we see it as a complete figure; strange indeed. Figures such as these coexist with other dynamical phenomena such as Fractals and Mandelbrot sets.

BACKGROUND

Chaos was pondered mathematically well over one hundred years ago, but it was not until computers were used to investigate the subject that the modern notion of chaos was born. All this happened in the early 1960s at Massachusetts Institute of Technology (MIT). It began when a weather man working at the institute wondered why the sea tides could be predicted exactly but not the weather. He set out to try and remedy this situation.

With access to the MIT’s computers and a set of math equations, he discovered the roots of modern chaos theory. Computer analysis indicated that only a slight change in just one of the many parameters in his weather equations brought about significant changes in the outcome.

A process romantically summed up by saying that the movement of a butterfly’s wing in South America can effect a weather change in Europe.

ELECTRONIC CHAOS

Can we as electronic constructors create our own electronic butterflies and strange attractors? The answer is yes and with not too much effort. There is the option of simulating a chaos circuit or actually building it.

THE SIMULATION ROUTE

If you have a copy of MicroSim’s Pspice (the evaluation MSDOS version is fine) it is easily used to load in the netlist given in **Table 1**. This program will generate time diagrams and strange attractors similar to the waveforms seen in Figures 1 and 2. Pspice software may be downloaded from the Edream BBS in the UK on telephone (01442) 256362. The book by Tuinenga listed at the end of this article is a reasonable introduction to Pspice and the netlisting of circuits.

The netlist is created from one of the first circuits used to analyse chaos. The circuit consists an inductor-capacitor (LC) arrangement that is connected to a negative resistor circuit provided by two op-amps. The full circuit is shown in **Figure 3**.

The circuit is called the Chua Diode Circuit after Professor Chua who created and analysed the arrangement in the 1980's.

Once the Pspice program is running, type in the netlist and save it. Most types of error are reported at this stage automatically. Nine times out of ten a reported problem is typographical. Then go to menu bar and select Analyse and run Pspice to simulate the circuit (the process takes about one minute on a 300-MHz machine running Windows 95 in DOS Shell mode). After the simulation is complete you are presented with a display screen. Press the enter key for Add_Trace then press key F4 and highlight V1 and Enter. A trace similar to Figure 1 is developed. To display the strange attractor, go to the X_axis, Enter, and then the X_variable and Enter. Now press F4 and select V2 and Enter. An image similar to Figure 2 is developed. Try a few of the other listed voltages or currents to develop different attractors.

The chaos test can be applied by changing the inductor value by, say, 1%, and then looking at the new time diagram: it changes shape. Change to the X-Y feature and note that the strange attractor diagram keeps its shape.

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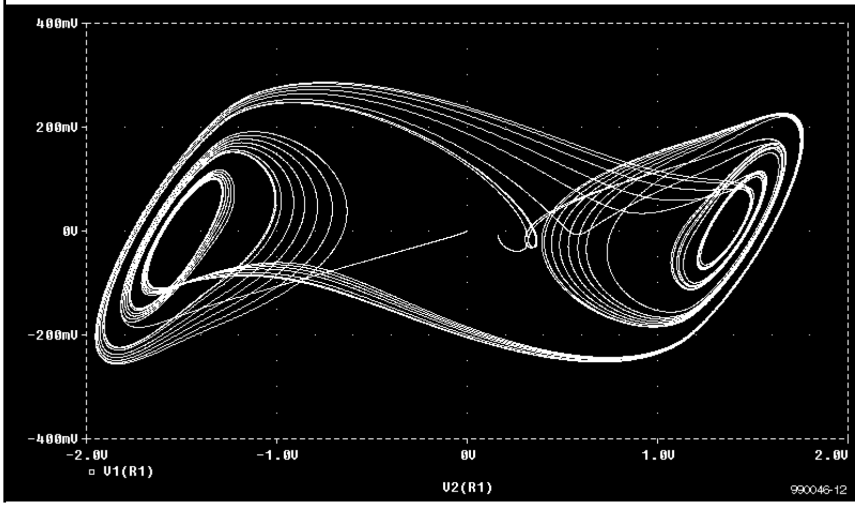
Figure 2. Strange attractor image often called the Lorenz 'butterfly'.



CHAOS UNDER WINDOWS

MicroSim do publish a Windows evaluation version of Pspice called DesignLab. It may be downloaded from their Web site at *http://www.microsim.com.*
If you choose to use this version rather than the DOS one described above, follow this procedure (Pspice v. 6.2):

Draw the circuit diagram.
Select ANALYSIS, SETUP, TRANSIENT.
Set transient to PRINT STEP = 20ns, FINAL TIME = 20ms, STEP CEILING = 500ns.
Activate SIMULATE.
Select X-axis settings in PROBE.
Select AXIS VARIABLE.
Select ALIAS NAMES.
Select V2(R1).

THE CONSTRUCTION ROUTE

If computers and simulation are not for you, then similar results may be obtained if the Chua diode circuit is actually built.

Component values and DC voltage are not critical. Instead of using two UA741 it is expedient to use a double op amp IC such as a LF412 or a TL052 or 62.

Table 1. Netlist of a circuit exhibiting chaotic behaviour (for Pspice DOS version).

Netlist some chaos

The netlist below is for the Chua diode circuit, and intended for DOS versions of Pspice.

```
Always have a netlist title on the 1st line. Comments after “;” are ignored by the program
R1 0 3 3.3k ; no value listed here is critical.
R2 3 4 22k
R3 2 4 22k
V+ 5 0 12V ; not critical say 10 to 15V
V– 0 6 12V
X1 2 3 5 6 4 UA741 ; the only op-amp available in version 5.2 but it works fine.
.LIB EVAL.LIB
R4 0 7 2.2k
R5 7 8 220
R6 2 8 220
X2 2 7 5 6 8 UA741
C1 2 0 10n ic=0V ; zero volts for initial conditions
C2 1 0 100n ic=0V
L 1 9 18m ; some interaction with this value and R1
R7 0 9 12 ; value is within the wire forming L1
R8 1 2 1.5k ;use a preset up to 2k
.tran 10u 20m 0 10u uic ; sets up the analysis times and to use initial conditions
.END ; must always end with an .end statement.
```

TESTING

Connect an oscilloscope probe to the top end of C_1 and adjust the controls for a trace. The signal is at audio frequency. A different chaotic waveform can be seen by connecting the probe to the top of C_2 . Switch the oscilloscope for X-Y mode and connect the signals from capacitors C_1 and C_2 to the X and Y inputs. Adjust the variable resistor (DOS: R8; WIN: R1) carefully to obtain the strange attractor shape seen in Figure 2.

CONCLUSION

Many people ask “What use is chaos?” A factitious answer might be “Why climb Everest?” The question is more usefully answered by the fact that chaos theory has been and is of great use in providing systems reliability. It has been a motivator to develop mathematical tools necessary to analyse and understand the problems associated with instability and oscillations in not only electronic circuits but also mechanical systems. Many complex circuits thought to be stable have been found, under certain conditions, to be unstable and exhibit chaos. Such a regime renders the system unserviceable with possible dire consequences. Another area of experimentation and research consists of using chaotic waveforms to modulate transmitted messages. Encrypting a message in this manner may yield a competitive advantage over current covert transmission techniques.

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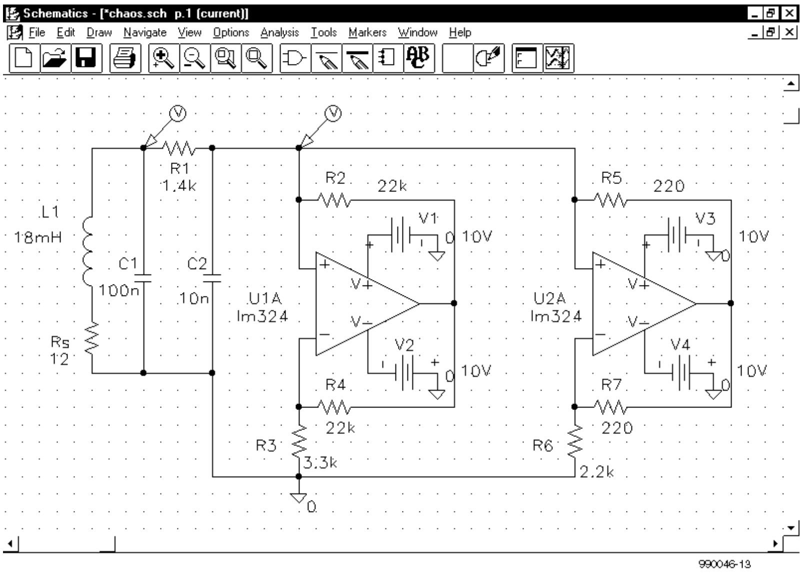
Figure 3. The Chua diode circuit (drawn using Pspice Windows version).



For further reading

The following books are well worth consulting for further information on the subject of chaos.

I Stewart, *Does God Play Dice?* Penguin Books 1990.

J Gleick, *Chaos*. Cardinal 1989.

P W Tuinenga, *SPICE*, Prentice-Hall 1992.

Edited by N Hall, *New Scientist Guide to Chaos*. Penguin Books 1992.

CONSTRUCTION GUIDELINES

Elektor Electronics (Publishing) does not provide **parts and components other than** PCBs, fornt panel foils and software on diskette or IC (not necessarily for all projects). Components are usually available form a number of retailers – see the adverts in the magazine.

Large and small values of components are indicated by means of one of the following prefixes :

E (exa) = 10^{18}
P (peta) = 10^{15}
T (tera) = 10^{12}
G (giga) = 10^{9}
M (mega) = 10^{6}
k (kilo) = 10^{3}
h (hecto) = 10^{2}
da (deca) = 10^{1}

a (atto) = 10^{-18}
f (femto) = 10^{-15}
p (pico) = 10^{-12}
n (nano) = 10^{-9}
µ (micro) = 10^{-6}
m (milli) = 10^{-3}
c (centi) = 10^{-2}
d (deci) = 10^{-1}

In some circuit diagrams, to avoid confusion, but contrary to IEC and BS recommandations, the value of components is given by substituting the relevant prefix for the decimal point. For example,

3k9 = 3.9 kΩ
4µ7 = 4.7 µF

Unless otherwise indicated, the tolerance of resistors is ±5% and their rating is ⅓–½ watt. The working voltage of capacitors is ≥ 50 V.

In **populating** a PCB, always start with the smallest passive components, that is, wire bridges, resistors and small capacitors; and then IC sockets, relays, electrolytic and other large capacitors, and connectors. Vulnerable semiconductors and ICS should be done last.

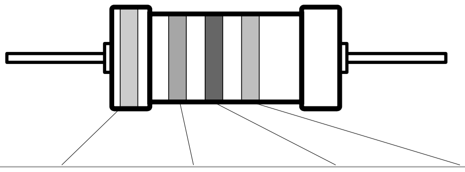
Soldering. Use a 15–30 W soldering iron with a fine tip and tin with a resin core (60/40) Insert the terminals of components in the board, bend them slightly, cut them short, and solder: wait 1–2 seconds for the tin to flow smoothly and remove the iron. Do not overheat, particularly when soldering ICS and semiconductors. Unsoldering is best done with a suction iron or special unsoldering braid.

Faultfinding. If the circuit does not work, carefully compare the populated board with the published component layout and parts list. Are all the components in the correct position? Has correct polarity been observed? Have the powerlines been reversed? Are all solder joints sound? Have any wire bridges been forgotten?

If voltage levels have been given on the circuit diagram, do those measured on the board match them – note that deviations up to ±10% from the specified values are acceptable.

Possible corrections to published projects are published from time to time in this magazine. Also, the readers letters column often contains useful comments/additions to the published projects.

The value of a resistor is indicated by a **colour code** as follows.



color	1st digit	2nd digit	mult. factor	tolerance
black	–	0	–	–
brown	1	1	$\times 10^1$	±1%
red	2	2	$\times 10^2$	±2%
orange	3	3	$\times 10^3$	–
yellow	4	4	$\times 10^4$	–
green	5	5	$\times 10^5$	±0,5%
blue	6	6	$\times 10^6$	–
violet	7	7	–	–
grey	8	8	–	–
white	9	9	–	–
gold	–	–	$\times 10^{-1}$	±5%
silver	–	–	$\times 10^{-2}$	±10%
none	–	–	–	±20%

Examples:
brown-red-brown-gold = 120 Ω, 5%
yellow-violet-orange-gold = 47 kΩ, 5%